VLA OBSERVATIONS OF A SAMPLE OF GALAXIES WITH HIGH FAR-INFRARED LUMINOSITIES

S. A. Eales and C. G. Wynn-Williams
University of Hawaii, Institute for Astronomy
Honolulu, Hawaii 96822 USA

C. A. Beichman
California Institute of Technology
Pasadena, California 91125 USA

ABSTRACT. We present preliminary results from a radio survey of galaxies detected by the IRAS minisurvey. We find that the main difference between galaxies selected in the far-infrared and those selected in the optical is that the former have higher radio luminosities and that the radio emission is more centrally concentrated. There is some evidence that the strong central radio sources in the galaxies selected in the infrared are due to star formation rather than to active nuclei. If the radio emission is caused by star formation, the star formation rate divided by the volume in which the star formation is occurring is 100-1000 times greater in the galaxies selected in the infrared than in the disks of normal galaxies.

INTRODUCTION

We present preliminary results from a VLA survey of the galaxies detected by the IRAS minisurvey. The sample consists of the galaxies in the area of the IRAS minisurvey with $M_{pg} \lesssim 18$ and $S_{60\mu m} \gtrsim 0.5$ Jy (Soifer et al. 1984), together with the minisurvey sources that did not have optical counterparts on the Palomar Sky Survey (Houck et al. 1984) but that were later found to be galaxies (Aaronson and Olszewski 1984, Houck et al. 1985). Eighty-eight of the 92 galaxies in the sample have redshifts, measured either at Mauna Kea Observatory or at Palomar (Lonsdale, private communication). Because it was selected in the infrared, the sample is biased towards galaxies with high far-infrared luminosities; 76% of the galaxies have $L_{fir} > 10^{10}$ $L_\odot$, compared with 5% of the spirals in an optical catalogue (Devereux, private communication).

We made 10-minute 'snapshot' observations of all the sources at 5 GHz with either the B- or C-array of the VLA, or with both. The data were reduced in a standard way, with extensive use being made of the CLEAN algorithm of Högbom (1974). To obtain structural information on the many sources that were just resolved by the VLA, we found the two-dimensional Gaussian brightness distributions that best represented the sources. This procedure gave us three structural parameters for each source: the distances between the half-intensity points along the major and minor axes and the position angle of the major axis. Flux densities were obtained either from the Gaussian fits or from integration over the maps in the vicinity of the significant components. Typical noise on the final maps was 0.2 mJy $beam^{-1}$.

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RESULTS

Of the 92 objects in the sample, 57 were detected by the VLA. An additional 10 were detected at 5 GHz with the Effelsberg telescope by the Bonn group (Klein, private communication). Eighteen of the 57 VLA detections were unresolved. There is one double-lobed radio source (0421+040; Beichman et al. 1985), and three of the pairs of interacting galaxies in the sample have radio sources coincident with both galaxies.

Fig. 1 shows an unrepresentative collection of radio maps; most typical is 0402+212, an undistinguished blob of emission at the position of the IRAS source.

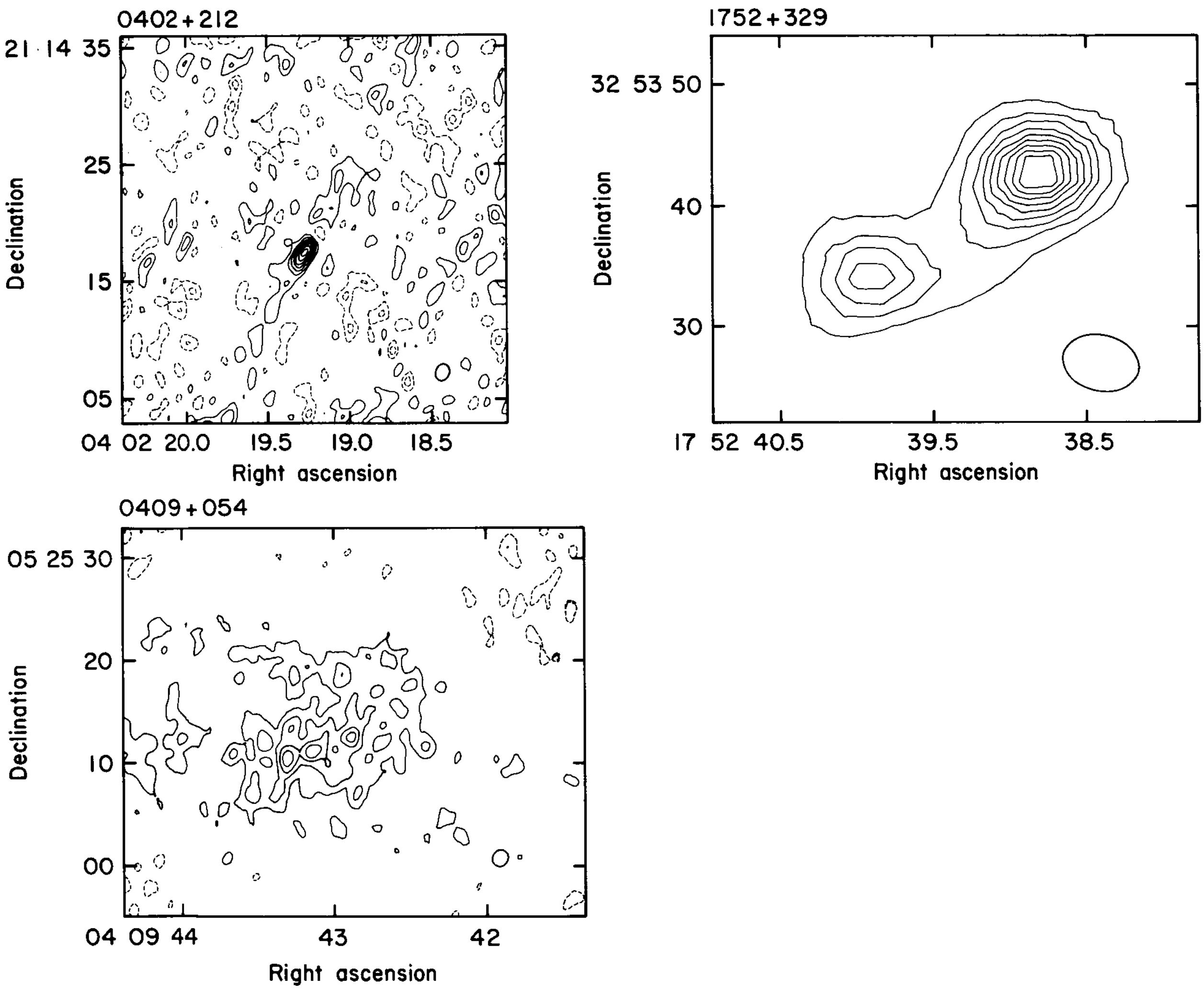

Figure 1. VLA maps of the IRAS sources 0402+212, 0409+054, and 1752+329. Negative contours are dashed, positive contours are solid lines, and the zero-level contour has been omitted. For the first two sources, the contour interval is 0.2 mJy beam^{-1}; for 1752+329, the contour interval is 7 mJy beam^{-1}. The ellipse in the bottom right-hand corner of each map shows the shape and size (FWHM) of the telescope beam. The 0409+054 source has a large physical size, ~7 kpc in diameter. 1752+329 is a pair of interacting galaxies. The radio peaks are coincident with the two galaxies.

DISCUSSION

Fig. 2 shows the P-D (radio luminosity-physical size) diagram for the minisurvey radio sources. The angular sizes used are mostly $(\theta_x\theta_y)^{1/2}$, where θ_x and θ_y are the distances between the half-intensity points along the major and minor axes of the best-fitting Gaussian brightness distribution. For sources with complex radio structures, angular sizes were measured off the maps between the lowest believable contours. The diagonal lines are lines of constant surface brightness. The undetected galaxies may have remained undetected because their radio luminosities are generally lower than those of the galaxies that were detected, or they may have similar radio luminosities but lower surface brightnesses and so fall on the P-D diagram to the right of the limiting surface brightness of the VLA--roughly the upper diagonal line in Fig. 2. The sizes of the sources range from 0.4 to 35 kpc, but most have sizes that bunch around the median, ~2 kpc.

How do the radio properties of these galaxies compare with those of galaxies selected from optical catalogues? Hummel (1980, 1981) used the Westerbork telescope to observe a large number of galaxies in the Reference Catalogue of Bright Galaxies. In Fig. 2 the horizontal lines show the luminosities above which 1% and 10% of Hummel's galaxies lie. The minisurvey radio sources are significantly more luminous (transforming between 5 GHz and 1.4 GHz, the frequency used by Hummel, by assuming $\alpha = 0.7$). The difference between the radio properties of infrared- and optically-selected galaxies becomes more marked when one considers that the radio emission from a typical minisurvey galaxy is coming from a much smaller physical region than the emission from a typical galaxy in an optical catalogue.

Another way to look at the difference between the radio properties of optically- and infrared-selected galaxies is to compare surface brightnesses; the minisurvey sources have surface brightnesses similar to those of the central sources in some well-known nearby galaxies (Fig. 2) (and much higher surface brightnesses than the disks of those galaxies) but higher luminosities and larger physical sizes. In the nine cases where we have accurate astrometry, to within the position errors (1-2 arcsec), the radio and optical centroids coincide, showing that the minisurvey radio sources occur in the centre of the galaxies.

What is causing the intense radio emission from the central regions of the minisurvey galaxies? Two possibilities, considering the high far-infrared luminosities, are star formation or active nuclei. The data are not good enough to reach a definite conclusion, but there are two arguments that suggest that the radio emission is caused by star formation.

The median physical size of a sample of Seyferts in which the radio emission is probably caused by collimated outflow from an active nucleus is only one-sixth that of the minisurvey galaxies (Ulvestad and Wilson 1984), which suggests that something different in the minisurvey galaxies is causing the radio emission. The second argument is that if the radio emission is caused by plasma beams from an active nucleus, the radio sources should be long and thin; which is not the case, as is shown in Fig. 3. There we plot for the minisurvey sources a histogram of eccentricity, defined as the distance between the half-intensity points along the major axis divided by the same distance along the

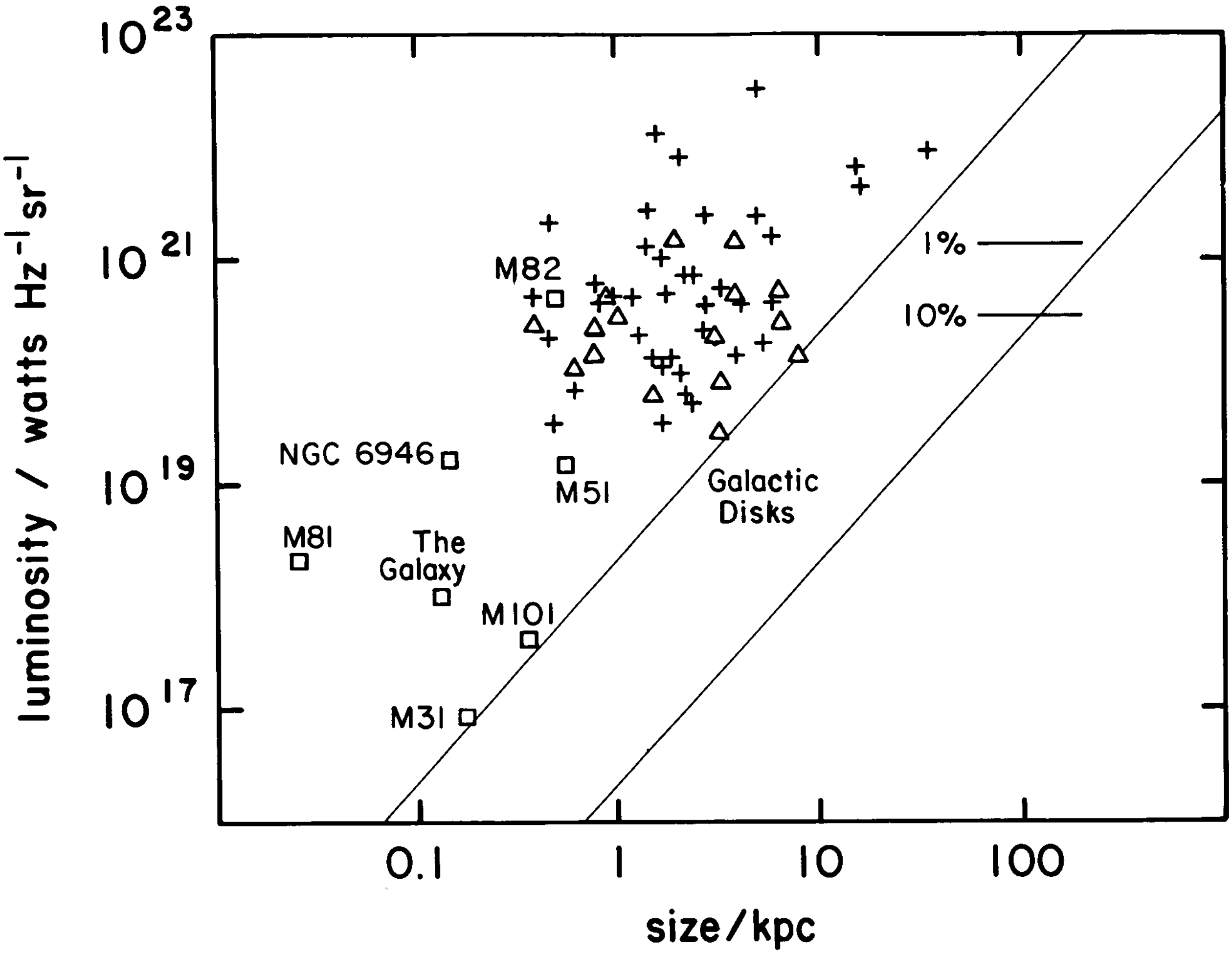

Figure 2. The luminosity-physical size diagram for the minisurvey sources. A Hubble constant of 75 km s^{-1} Mpc^{-1} has been assumed. Δ indicates an upper limit to the physical size. The squares show the positions of the central sources in some well-known nearby galaxies (Ekers 1975). The diagonal lines are lines of constant surface brightness. Galaxy disks have surface brightnesses that lie between these lines. The horizontal lines show the luminosities above which 1% and 10% of Hummel's galaxies lie.

minor axis. The median eccentricity is not much larger than the median expected from the effect of projection, if the sources consisted of thin circular disks.

A measure of the intensity of a starburst is the star formation rate divided by the volume in which the star formation is occurring, call this ε. If the radio emission is caused indirectly by star formation and directly by supernova remnants, $\varepsilon \propto$ radio surface brightness and is 100-1000 times greater than in the disks of normal galaxies.

Although star formation may be the cause of the radio emission in most of the minisurvey galaxies, there are a few galaxies in which the data point to an active nucleus. M82 is at once the prototype starburst and also the prototype

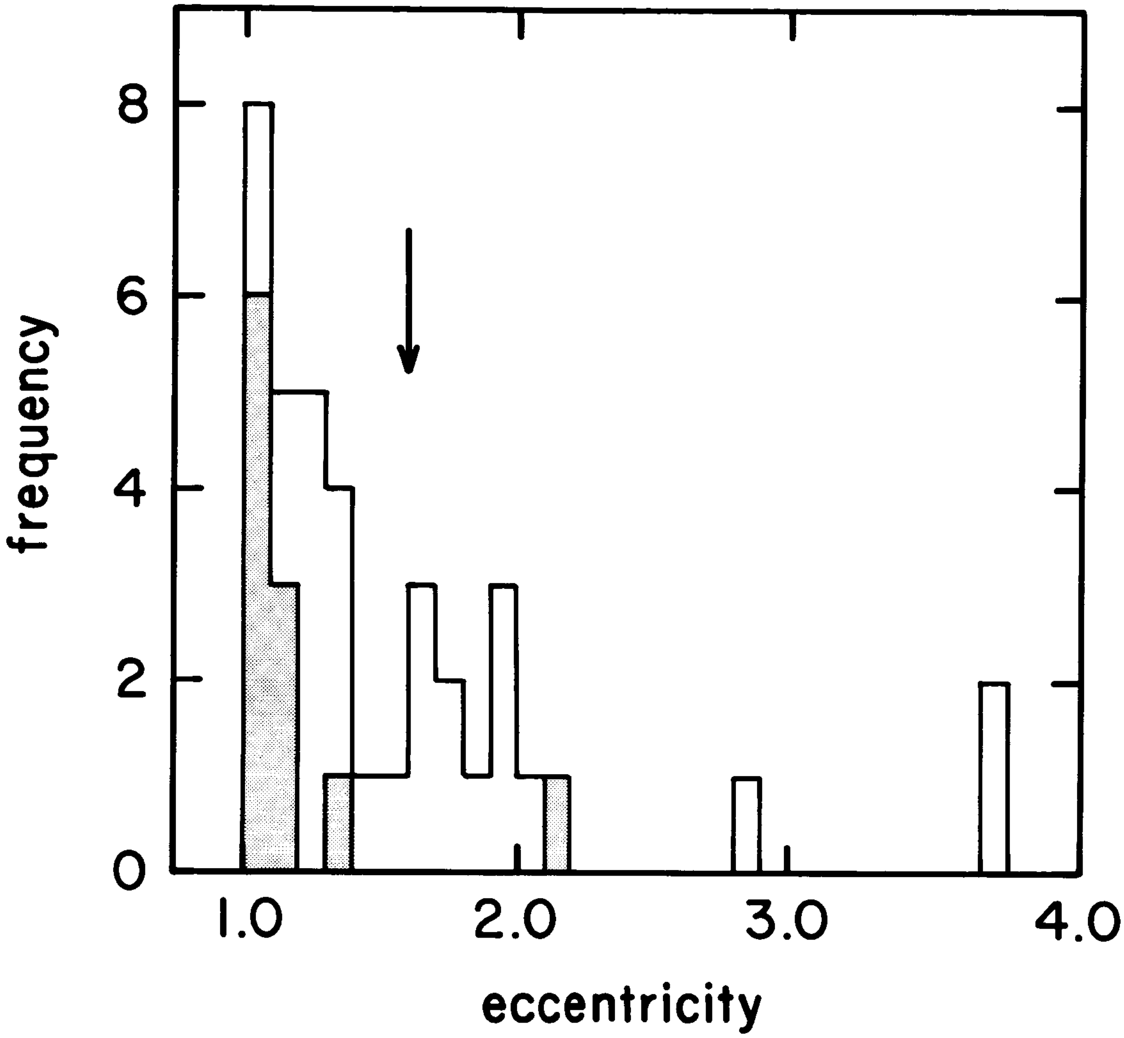

Figure 3. A histogram of eccentricity for the minisurvey galaxies. The hatching indicates lower limits. The median eccentricity is shown for those sources that have exact measurements. For comparison, the median expected from the effect of projection if the sources were just thin circular disks is 1.3.

exploding galaxy (Lynds and Sandage 1963; Bland and Tully, in preparation). Chevalier and Clegg (1985) have suggested that this is not a coincidence: that the explosion is caused by the large number of supernovae occurring in the starburst at the centre of the galaxy. We speculate that for a starburst, ε cannot exceed its value for M82, otherwise an explosion occurs. Three minisurvey sources have, however, higher values of ε, so these may be active nuclei rather than starbursts. One minisurvey source is certainly caused by outflow from an active nucleus--the double-lobed radio source 0421+040 (Beichman et al. 1985).

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